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by

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INTENSITY OPTICAL CORRELATION THROUGH OPTICAL DIFFERENTIATION PREPROCESSING

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A high discrimination intensity optical correlation system is presented in this article. By using a lensless spacial differentiation filter to achieve edge enhancement for the input images, the discrimination of the intensity optical correlator with the Fresnel holographic filter is improved. Theoretical analysis and experimental demonstration are given.

The use of a Fresnel holographic filter (FHF) to achieve intensity optical correlation discrimination has been studied in some depth[1,2,3]. This new type of wave filter has a number of advantages.

However, using a FHF intensity optical correlation system calculates the correlation of light intensity factors and not of complex amplitude factors. Therefore, it reduces the discrimination of the correlation test. Also, for many real objects such as aircraft and tanks, their Fresnel spectrums all contain a fairly large amount of frequency nulls, and their autocorrelation distribution is a fairly large diffused spot. This makes it even more necessary to solve the problem of characteristic recognition differentiation (discrimination). The use of optical differential preprocessing to enhance the edges of images, because it eliminates the frequency nulls in the center of the image and some low frequencies, it makes the higher frequency signals stand out and sharpens the autocorrelation peaks, which improves the image discrimination. This article simply combines an ordinary FHF intensity optical correlation system and an optical differentiation

preprocessing system, and obtained an optical correlation testing system which has both flexibility and high discrimination.

II: THEORETICAL ANALYSIS

Considering only the one dimensional situation, expanding the real factor T(∞) which expresses the intensity distribution of a characteristic signal to where it has cosine factors of frequency f_n superimposed.

$$T(x) = \sum_{n=-\infty}^{+\infty} I_n(f_n)\,\mathrm{rect}\left(\frac{x}{2L}\right)\cos(2\pi f_n x) \tag{1}$$

In this equation, $I_n f(_n)$ are the weighting of the nth level cosine component. 2L is the sampling interval. For the purpose of simplifying matters, here we only consider the effects of frequency null components on correlation peaks. The above equation can be resolved as follows:

$$T(x) = I_c\,\mathrm{rect}\left(\frac{x}{2L}\right) + \sum_{n\neq 0} I_n(f_n)\,\mathrm{rect}\left(\frac{x}{2L}\right)\cos(2\pi f_n x) \tag{2}$$

In this equation, I_o is the frequency null component. The characteristic signal intensity autocorrelation distribution is:

$$\begin{aligned} I(u) &= \int_{-\infty}^{+\infty} T(x)T^*(x+u)\,dx \\ &= \frac{|I_0|^2}{2L}\Lambda\left(\frac{u}{2L}\right) + \sum_{n\neq 0} |I_n(f_n)|^2 \int_{-\infty}^{+\infty} \mathrm{rect}\left(\frac{x}{2L}\right)\cdot \mathrm{rect}\left(\frac{x+u}{2L}\right) \\ &\quad \cdot \cos(2\pi f_n x)\cos[2\pi f_n(x+u)]\,dx \end{aligned} \tag{3}$$

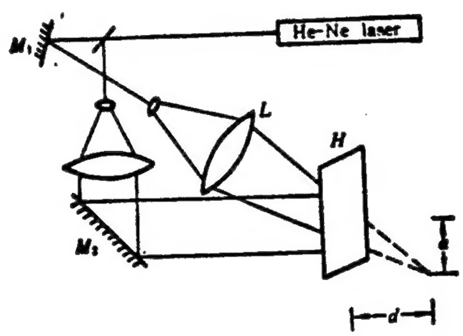
In this formula, the triangular factor $\Lambda\left(\frac{u}{2L}\right)$n the first item is one background provided by frequency null components. Compared to summation items, it is a slowly changing factor. The conditions to establish equation (3) are to ignore the effects of cross correlation between the frequencies in different space.

We qualitatively analyzed the effects of $\left(\frac{u}{2L}\right)$ on the sharpness of the correlation peaks. If we set the height of the correlation peaks of the summation items in equation (3) at 2h, half intensity width is a distance of h from the peak, and $\Lambda\left(\frac{u}{2L}\right)$ forms a slowly changing background with an altitude of 2H. Thus, with a background, the distance from the half intensity to the peak value

point is h+H. In a condition corresponding to no background noise, the half intensity point shifts the H distance down to bottom of the outline, so the half intensity width is increased, and the corresponding peak becomes wider. Furthermore, the larger the frequency null component (that is, the higher H is), the wider the corresponding peak. Some low frequency components in the image will also cause the same thing. In order to obtain a sharper corresponding peak, it is necessary to eliminate or reduce the frequency null components and the low frequency components in the image, and boundary intensity optical differential preprocessing is one feasible effective way of doing this.

III: INTENSITY OPTICAL CORRELATION OF DIFFERENTIAL IMAGES

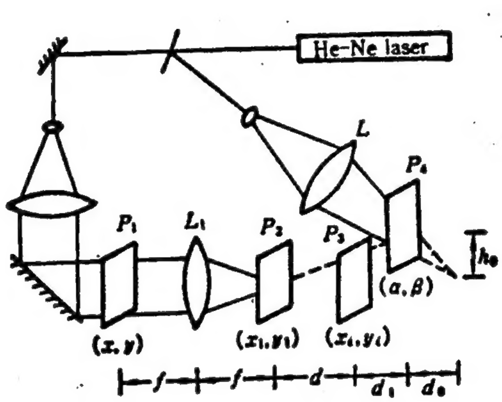
Fig. 1. Optical Path of Lensless Spacial Differentiation Filter



In order to achieve intensity optical correlation discrimination of differential images, it is necessary to first of all make a spacial differentiation filter to use for optical differentiation preprocessing of characteristic objects or input objects to obtain an edge enhanced differential image. We used a lensless space differentiation filter as reported by Qin Qiuxiang[5] to perform the differentiation preprocessing. The lensless space differentiation filter recording equipment is shown in Figure 1. It is a differentiation filter which uses double exposure by one parallel wave and one spherical wave for recording. The location of the focal point of the focused spherical wave is indicated by

(d) and (a) in Figure 1. The parallel wave perpendicular to the hologram H is exposed first. Prior to the second exposure, the direction of the parallel wave is altered by a minute angle $\Delta\theta$, and the two exposures occur at the same time. With appropriate developing and fixing, we obtain the needed lensless spacial differentiation wave filter. A two dimensional lens spacial differentiation wave filter can be made using similar methods.

Fig. 2: Recording Arrangement of the Fresnel Holographic Filter for Differential Images



The differential image Fresnel Holographic filter was made using the optical circuits shown in Figure 2. The characteristic object g(x,y) entered through plane P_1, and a lensless spacial differentiation filter is placed at the focal plane P_2 behind lens L_1. By appropriately adjusting the location of the differentiation filter (a distance $b=\lambda/2\Delta\theta$ along x_1, it is possible to obtain on plane P_3 an edge enhanced differential image.

$$g_i(x_i, y_i) = g(x, y) * [\delta(x+a+b+\lambda\theta f, y) - \delta(x+a+b, y)] \tag{4}$$

In this equation, * indicates convolutional computation, (x, y) and (x_i, y_i) are the coordinates of the entrance plane P_1 and the differential output plane P_3 respectively. Using this differential image as the object light, and placing hologram plates on the P_4 plane for d_1 behind it, using the focus of the reference light to record the differential image's Fresnel holographic filter. The

focal point of the focussed reference light is at a distance of d_o from the holographic plate and a distance of h_o from the system's light axis. Under Fresnel approximation, the holographic plate object light wave and reference light wave are obtained as follow:

$$O(\alpha,\ \beta)=C_1\iint_{-\infty}^{+\infty} g_i(x_i,\ y_i)e^{\frac{j\pi}{\lambda d_1}[(\alpha-x_i)^2+(\beta-y_i)^2]}dx_i\,dy_i \tag{5}$$

$$R(\alpha,\ \beta)=C_2 e^{\frac{-j\pi}{\lambda d_0}[(\alpha-h_0)^2+\beta^2]} \tag{6}$$

Herein, C_1 and C_2 are complex constants, and $(\alpha,\ \beta)$ are the coordinates of plate P_4. Through appropriate exposure and developing, it is possible to obtain a differentiation filter Fresnel holographic filter. The amplitude transmissivity is

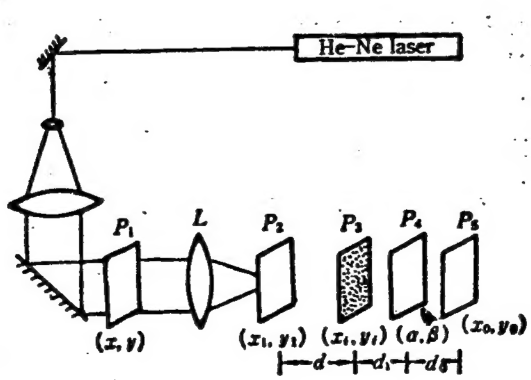
$$T(\alpha,\ \beta)\propto|R(\alpha,\ \beta)+O(\alpha,\ \beta)|^2=|R|^2+|O|^2+R^*O+RO^* \tag{7}$$

In these four diffractions, one item which is related to optical correlation computation is

$$\begin{aligned} T(\alpha,\ \beta) & \\ &=R(\alpha,\ \beta)O^*(\alpha,\ \beta) \\ &=C_3 e^{\frac{-j\pi}{\lambda d_0}[(\alpha-h_0)+\beta^2]} \\ &\times\iint_{-\infty}^{+\infty} g_i^*(x_i,\ y_i)e^{\frac{-j\pi}{\lambda d_1}[(\alpha-x_i)^2+(\beta-y_i)^2]}dx_i dy_i \end{aligned} \tag{8}$$

Herein, C_3 is also a complex constant.

Fig. 3: Intensity Optical Correlation System for Differential Images



The optical circuitry of differential image intensity optical correlation systems is shown in Figure 3. This system is composed of an optical differentiation preprocessor system and an intensity optical correlation system. The object to be discerned (f(x,y) enters through plane P_1, and on frequency spectrum plane P_2 a lensless spacial differentiation filter is placed. Through this optical differentiation preprocessing subsystem, at the plane it is possible to obtain edge enhanced differential image $f_{\mapsto}(x_{\mapsto}, y_{\mapsto})$. At plane P_3 a constantly moving diffusion scattering screen is placed to serve as the input plane for the intensity optical correlation subsystem. At the same time, the spacially correlated light is converted to spacially non-correlated light. The Fresnel holographic filter made as described above is placed on space wave filter plane P_4. The distance between plane P_4 and P_3 is d_1. The intensity optical correlation system is linear for the incoming light intensity, thus signifying that the physical quantity of the relationship between the system input and output is a function of the irradiation pulse response. We first calculated the system's pulse response function. Assume that a single pulse $\delta(x_i - x', y_i - y')$ enters P_3 of the correlation system. Its light wave field is a single spherical wave on plane P_4. Then the light wave field just emitted from the correlation filter plane is

$$E(\alpha, \beta) = e^{\frac{j\pi}{\lambda d_1}[(\alpha - x')^2 + (\beta - y')^2]} T(\alpha, \beta) \tag{9}$$

The correlation filter pulse response factor is equation (9) transmitted to the Fresnel diffraction of plane P_5:

$$h(x_0, y_0; x', y') = \iint_{-\infty}^{+\infty} E(\alpha, \beta) e^{\frac{j\pi}{\lambda d_0}[(x_0 - \alpha)^2 + (y_0 - \beta)^2]} \, d\alpha \, d\beta \tag{10}$$

Substituting equations (8) and (9) in equation (10) and differentiating. Under conditions $d_1 = d_0$ we can obtain

$$h(x_0, y_0; x', y') = g_i^*(x_0 + x' - h_0, y_0 + y') \tag{11}$$

The irradiation pulse response function is the square of the pulse response function module.

$$h_i(x_0, y_0; x', y') = |g_i^*(x_0 + x' - h_0, y_0 + y')|^2 \tag{12}$$

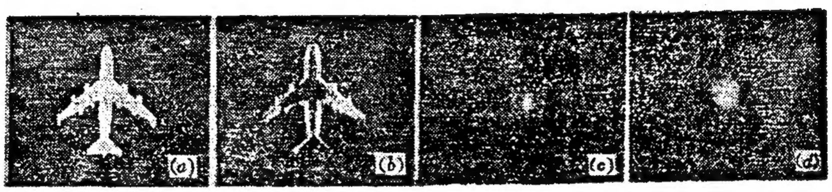
The system output irradiance is the convolution of the irradiance of the correlation input function and the irradiation pulse response function:

$$I(x_0, y_0) = \iint_{-\infty}^{+\infty} |f_i(x_i, y_i)|^2 |g_i^*(x_0 + x_i - h_0, y_0 + y_i)|^2 dx_i\, dy_i \qquad (13)$$

This, then, is the computation of the intensity correlation of boundary enhanced differentiated image.

IV: EXPERIMENTAL DEMONSTRATION AND RESULTS

Fig. 4:



The correlation light source we used in our experiments was a 60mW He-Ne laser. The recording medium was a HP 633 model holographic plate produced by the Tianjin Mircotechnology Development Company. We used special "slow developing" processing technology, and the diffraction efficiency of this type of holographic plate was 30 to 40 percent. In our experiment, we first used the picture in 4(a) as the input object or characteristic object. It was optically differentiation preprocessed through a lensless spacial differentiation filter, obtaining the boundary enhanced differential image shown in 4(b). This differential image achieved intensity light correlation discrimination by using a Fresnel holographic wave filter, obtaining the autocorrelated result shown in 4(c). As an illustrative comparison, figure 4(d) shows the intensity light correlation results of the original input image without differentiation preprocessing. We can see that there is marked improvement in the discrimination.

In order to quantitatively explain the improvement in discrimination, we also performed computation of the simulation

experiment. We use the English letters "O", "O'" and "T" as the target object, using a computer to simulate the intensity correlation system discrimination of the letter "O". The discrimination Δ was used to define the corresponding value of the height differential between the autocorrelated peaks and cross correlated peaks.

$$\Delta = \frac{h_{auto} - h_{cross}}{h_{auto}} \times 100\% \tag{14}$$

In this equation, H_{auto} and H_{cross} refer to the height of the autocorrelated peaks and the height of the cross correlated peaks respectively. In our experiment, we used 256 X 256 dot high speed Fournier conversion processing of a 128 by 128 two dimensional image (English letters). Without differential preprocessing, the discrimination between "O" and "O'" was Δ=1.2% and for discrimination between "O" and "T" it was Δ=21.0%. However, with differential preprocessing, the discrimination between "O" and "O'" was 12.6 and between "O" and "T" it was 48.5%. we can see that discrimination is greatly improved, and the smaller the difference between the two images, as in "O" and "O'", the more noticeable the improvement. Table 1 provides the specific data from the computer simulation experiment. The correlation peak height data has been normalized.

Table 1: Correlation Discrimination with Original Images and Differential images respectively.

Input image	correlation	correlation peak qeight	discriminating force
Original image O and C	$O \circledast O$	1.000	1.2
	$O \circledast C$	0.988	
Differential image O' and C'	$O' \circledast O'$	0.719	12.6
	$O' \circledast C'$	0.627	
Original image O and T	$O \circledast O$	1.000	21.0
	$O \circledast T$	0.790	
Differetial image O' and T'	$O \circledast' O'$	0.719	48.5
	$O' \circledast T'$	0.370	

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